DEVELOPING AN AUTOMATIC WLAN-BASED GPS MONITORING SYSTEM

Reducing the Costs of Geodetic Monitoring

Monitoring is one of the main tasks in engineering geodesy. Apart from tachymeters, only GNSS receivers can measure 3-dimensional positions automatically and continuously. Geodetic dual-frequency receivers are expensive, generally costing over EUR20,000. In recent years, however, single-frequency receivers available for less than EUR100 each have proved capable of achieving almost the same accuracy as geodetic ones, thus representing a potential alternative for geodetic receivers. This article introduces the automatic GPS monitoring system which has been developed at the Institute of Engineering Geodesy (IIGS) and presents its initial results.

An overview of the low-cost GPS monitoring system's architecture is shown in Figure 1. The test system consists of three stations: a master (central station) and two clients. The master continuously collects raw data from the two clients via WLAN in real time. The data from all stations are transferred to the central station's computer for processing. Figure 2 shows the components of one autonomous station. Each station has a wireless CabLynx router which has been configured to transfer the data via a wireless mesh network (WMN). Within the WMN, data from the clients can automatically find their own path to reach the master, and the master automatically assigns IP addresses to the clients. Even if one client router could not operate, the remaining clients could still communicate with each other and transfer their data to the master, meaning that the self-organised and self-healing mesh

Li Zhang has been research associate (Dipl.-Ing.) at the Institute of Engineering Geodesy (University of Stuttgart) since 2009, where she previously studied geodesy for 5 years.

✉ li.zhang@ingeo.uni-stuttgart.de

Mathias Stange has been on the technical staff (Dipl.-Ing.) at the Institute of Engineering Geodesy (University of Stuttgart) since 2010. He previously studied geodesy at the University of Applied Sciences Berlin for 4 years.

✉ mathias.stange@ingeo.uni-stuttgart.de

Volker Schwieger has been professor and head of the Institute of Engineering Geodesy since 2010. He completed his habilitation at the University of Stuttgart in 2004 and his Dr.-Ing. in geodesy at the University of Hannover in 1998, where he previously studied geodesy. In 2012, he was elected chair-elect of FIG Commission 5 'Positioning and Measurement'.

✉ volker.schwieger@ingeo.uni-stuttgart.de

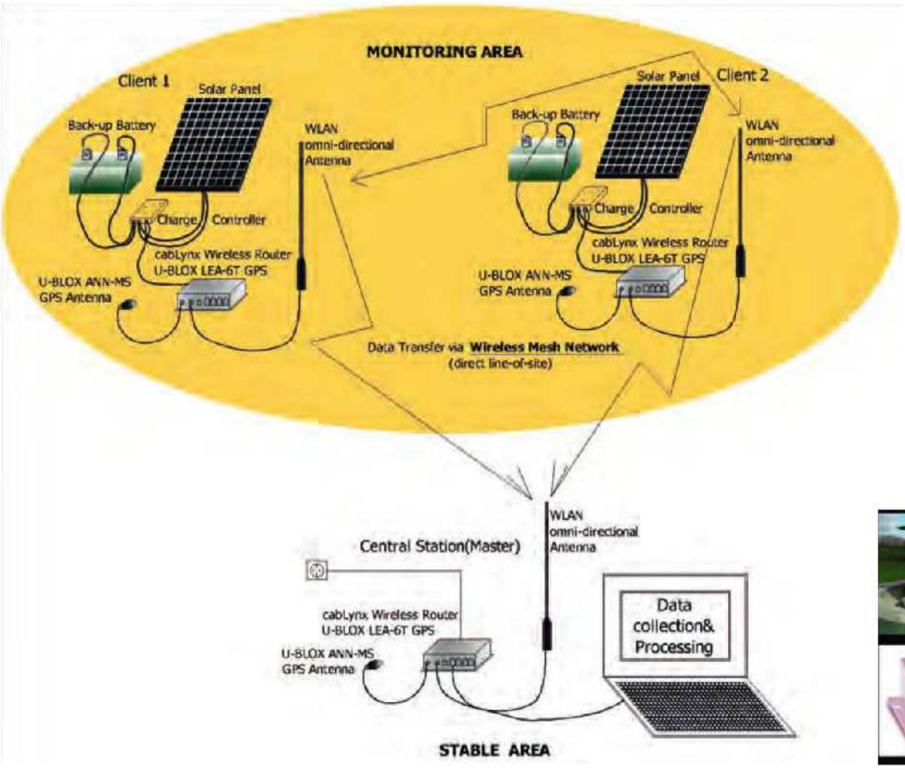

Figure 1, System architecture.

Figure 2, System components of one autonomous station.

network provides a higher reliability and limits redundancy.

Since the network is self-organised and the data transmission direction is variable and previously unknown, an omnidirectional antenna is necessary. The system's WLAN communication range has been tested up to 2.6km (the longest distance available in the test area). Because the line of sight is very important for the WLAN communication, the WLAN antennas should be set up as high as possible during measurements in order to reduce or preferably eliminate obstructions between them.
Additionally, to ensure that the system can run continuously and autonomously, each station's power supply is provided with one solar panel, one charge controller and one back-up battery. The most important parts of the router are the u-blox GPS antenna ANN-MS and the latest-generation u-blox GPS receiver LEA-6T. The GPS antenna is shielded with a ground plate to reduce undesirable multipath effects (see Figure 2, top left). By using the LEA-6T receiver, it is possible to output the GPS raw data in binary format. These basics are preconditions for reaching results with centimetre-level accuracy.

AUTOMATIC DATA ACQUISITION AND DATA PROCESSING

Data collection is also realised automatically by a C-program (see Figure 3). The raw data from the routers are identified by the IP address from which they were sent and stored directly in different address-specific files on the computer. The raw data are stored in proprietary binary format (UBX format) that is transformed into receiver-independent exchange format (RINEX format) by the freeware TEQC for further processing. The problem of calculating the baseline (coordinates of the rover stations related to the reference station) is solved by the Wa1 software which was developed by Prof.-Ing. Lambert Wanninger from the Technical University of Dresden. The data processing runs automatically and the results are generated in near real time by a bash script which can be run periodically (e.g. every 20 minutes). Then the final results and the original raw data of this time interval will be saved. The whole system is running under Linux.

INITIAL RESULTS

Several tests were conducted in 2011 to evaluate the accuracy of this system depending on observation time and baseline length as well as shadowing conditions. This article presents a summary of the results of the test which was carried out in November 2011 in Vaihingen, Stuttgart (see Figure 4).

In this area, there are several pillars, whose coordinates in WGS 84 are known down to less than one millimetre. Each session took about one hour. As shown in Figure 4, the baseline varies from about 250 to 1,100 metres. Additionally, the master had a shadowing-free environment while Client1 (close to the forest) and Client2 (close to buildings and trees) were trapped in a shadowing environment.

In order to analyse the accuracy, the given and the measured values of baselines are compared (see

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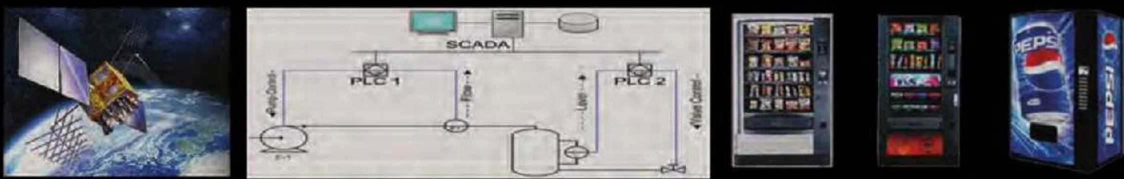

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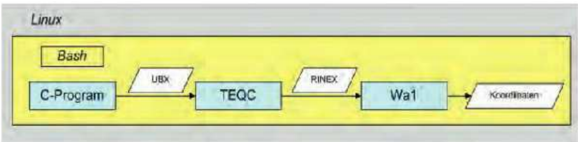
Figure 5). They are calculated from the given coordinates and the measurement results enabling their coordinates' differences $\Delta d\lambda$ $\Delta d\varphi$ Δdh in WGS 84 to be determined. For ease of interpretation, they are converted into the local ellipsoidal coordinate system meaning north, east and height.

In order to analyse the accuracy depending on the length of observation time, the observation time interval of one hour was divided into several shorter time intervals: 5, 10, 15, 20, 25 and 30 minutes. The results from the 5-minute intervals are inaccurate and unreliable. Only about 50% of the measurements have solutions with fixed ambiguities. For this reason, only the results from the 10 to 30-minute time intervals will be presented.

The standard deviations calculated by the Wa1 software are better than 1mm, but the standard deviations obtained by the GNSS adjustment programmes are frequently too optimistic. For this reason, the results of the different time intervals are compared to each other meaning, for example, that there are 6 resulting baselines for the 10-minute time intervals. The mean value and the standard deviation of these 6 results are calculated. The mean value can be regarded as the reproducibility (absolute) accuracy compared with the true value, and the standard deviation can be regarded as the repeatability (relative) accuracy for the stability of the measurements. Furthermore, only the fixed solutions are taken for the data analysis, so the 'Reliability' value is defined as the percentage of the fixed solutions of the total results (see Table 1 for the results from one session).

The mean values and the standard deviations do not become much better with longer observation time (from 10 minutes upwards). The standard deviations are almost all less than 1cm if the float solutions

Figure 3, Automatic data collection and processing.



Time	Baseline	Mean [mm]			Standard Deviation [mm]			Reliability
Interval		mΔdN	mΔdE	mΔdh	sΔdN	sΔdE	sΔdh	[%]
10min	Master&Client1	**-13.7**	**-3.7**	-13.0	2.5	1.6	10.5	83.33
15min		**-14.3**	-4.1	-15.4	2.1	2.4	7.0	75.00
20min		**-13.3**	-4.3	-12.7	1.9	1.5	8.6	100.00
25min		**-13.7**	-4.8	-12.3	1.3	2.0	9.1	100.00
30min		**-13.7**	-4.5	-13.3	1.0	2.4	9.5	100.00
10min	Master&Client2	**-17.5**	**28.9**	-9.8	2.4	1.2	7.9	83.33
15min		**-16.7**	**29.3**	-7.8	0.3	0.8	5.6	75.00
20min		**-18.0**	**28.8**	-10.4	2.7	1.0	7.7	100.00
25min		**-17.6**	**28.8**	-9.6	2.0	1.7	9.6	100.00
30min		**-17.7**	**28.9**	-10.0	2.4	1.2	8.4	100.00
10min	Client1&Client2	-5.3	**33.6**	-0.5	2.1	2.2	7.7	50.00
15min		-4.6	**32.4**	-0.9	2.8	1.8	3.3	50.00
20min		-5.7	**33.5**	-2.4	0.9	1.5	3.6	66.67
25min		**-6.3**	**32.4**	-1.7	0.3	3.1	1.2	100.00
30min		**-6.5**	**32.3**	-0.8	0.1	2.4	1.6	100.00

Table 1, Accuracy and reliability analysis.

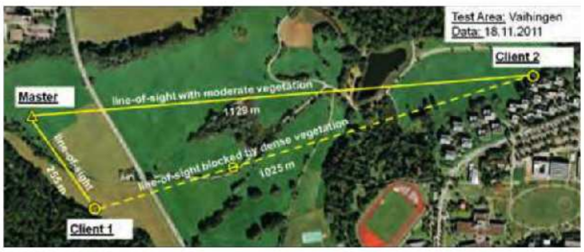
are neglected. Those of the heights are worse than that in the horizontal position, which is normal for GPS measurements.

The results of the baseline Client1-Client2 are quite unreliable and the solution of 10 and 15-minute intervals are not completely fixed for all the baselines because both clients are in a shadowing environment. The mean values in all the components show deviations less than 3.5cm. Obviously some systematic errors are still occurring. The coordinates' components where systematic errors are identified by statistical means are shown in bold italics in Table 1. The first possible explanation for these systematic errors is that the calibration files used for data processing are obtained by an antenna without the constructed ground plate. In our measurements, the antennas are shielded with a ground plate. Furthermore, the same calibration file was used in data processing for all the antennas. It is probable that the antennas are different and individual calibrations of each antenna with ground plate are necessary.

CONCLUSION AND OUTLOOK

This article has introduced the automatic, low-cost GPS monitoring system using WLAN communication developed at IIGS. The WLAN was tested regarding the range and line of sight as well as the wireless mesh network. This system's WLAN

Figure 4, Test scenarios in Vaihingen, Stuttgart.



communication range may be greater than 2.6km in line-of-sight case. The initial results of testing the positioning accuracy were then presented. Despite smaller standard deviations, the maximum systematic deviations are 3.5cm. For monitoring tasks, the system should achieve millimetre-level precision so the accuracy needs to be improved. The development of an improved ground plate and a 'low-cost' choke ring may reduce systematic effects, especially multipath. Alternative low-cost antennas will be tested, and antenna calibration is essential for all these tests. It is also planned to expand the system to enable it to be remotely controlled via the internet. In the future, if GLONASS, Galileo and Compass are added to GNSS receivers, availability and reliability will increase. If such possibilities will also be included in the low-cost segment, the economic potential of low-cost GNSS systems for monitoring tasks will become even greater.

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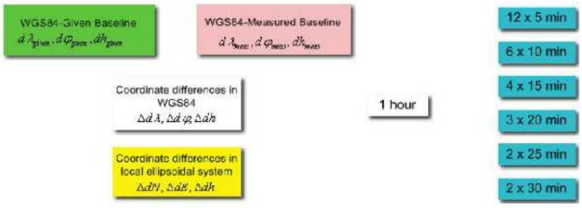

▲ *Figure 5, Accuracy analysis procedure.*

FURTHER READING

- Glabsch, J., Heunecke, O., Schuhbäck, S. (2009): Monitoring of the Hornbergl landslide using recently developed low-cost GNSS sensor network. *Journal of Applied Geodesy*, de Gruyter Verlag, Issue 4, 2009.
- Schwieger, V (2009): Accurate High-sensitivity GPS for Short Baselines. FIG Working Week, Eilat, Israel, 3-8 May 2009
- Schwieger, V., Zhang, L. (2012): Automatisches geodätisches Monitoring mit Low-Cost GNSS. *Messtechnik im Bauwesen*, Wilhelm Ernst & Sohn Special, Berlin, 2012.
- Zhang, L., Stange, M., Schwieger, V. (2012): Automatic Low-Cost GPS Monitoring System Using WLAN Communication. FIG Working Week 2012. 6-10 May 2012, Rome, Italy (full paper)